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ADVANCED TETHERED VEHICLE LIGHTWEIGHT HANDLING SYSTEM DEVELOPMENT AND TESTING

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ABSTRACT

This paper describes the development and testing of the lightweight Surface Handling System (SHS) for the Advanced Tethered Vehicle (ATV), a tethered, 13,000-lb ROV with a sea state 3 launch/recover capability. The SHS features a pivoting A-frame and a tension compensating ram tensioner. Use of an A-frame greatly reduces the weight and complexity of the handling system. The ram tensioner prevents snap-loading of the lift-line during launch and recovery, and snap-loading of the tether while at depth. Preliminary testing used a dummy vehicle in 63 launches and recoveries in up to sea state 3. Final testing with the vehicle culminated with a successful 20,600-ft (6280-m) dive in high sea state 3 conditions.

INTRODUCTION

Objective

The objective of this program was to develop a lightweight handling system for a deep ocean, unmanned tethered vehicle that can be used on a ship of opportunity.

Background

The Advanced Tethered Vehicle (ATV) will be used by the US Navy as a work vehicle in depths to 20,000 ft (6100 m). The ATV is a successor to the developmental Remote Underwater Work System (RUWS). For surface handling, the RUWS used the Motion Compensated Deck Handling System (MCDHS) (Yumori, 1979). The RUWS configuration consisted of a Primary Cable Termination (PCT), and a vehicle that were mated during ascent and descent. At working depth, they were unmated while the vehicle did its mission. The PCT and vehicle were connected by a 1000-ft tether. An active motion compensation system was required to prevent snap-loading in the tether and to reduce termination motion to ease vehicle docking. The MCDHS was heavy (110,000 lb) and complex. The ATV handling system needed to be more easily transportable and simpler than the MCDHS.

The Naval Civil Engineering Laboratory (NCEL) analyzed the cable dynamics of a buoyant whip configuration that does not require an MCDHS. This configuration uses flotation on the tether near the vehicle to form a "S"-shaped whip that decouples the surface platform motion from the vehicle. The buoyant whip was first used on the Cable-controlled Underwater Recovery Vehicle (CURV). NCEL used its program SNAPLD (Liu and Jordan, 1982), which is a time-domain, two-dimensional model. The motion input was a sea state 4 for a 196-ft support boat. The analysis showed that some tension compensation was needed. NCEL found that snap-loading can occur at all depths greater than 2500 ft and that severe snap-loading can occur with a flooded vehicle at a shallow depth.

In 1985, a prototype ATV using a buoyant whip was operated in 12,000-ft deep waters, 12-nmi west of Kailua-Kona on the island of Hawaii. The MCDHS was used for surface handling. A sea state 4 was simulated by biasing the feedback on the MCDHS active motion compensation system. There was some relatively small tether snap-loading. The MCDHS also tested passive tension compensation. The tether whip did not significantly degrade the vehicle speed and station-keeping ability. Based on these tests, it was decided that the MCDHS could be replaced with a lightweight handling system using an A-frame and a passive motion compensation system for a 45,000-lb weight savings. The MCDHS traction winch and storage drum were incorporated into the new system.

REQUIREMENTS

The ATV Surface Handling System (SHS) must launch and recover the vehicle in sea state 3. The vehicle dimensions are

Width with thrusters	9.6 ft
Height including bale	6.9 ft
Length with tools	16.5 ft
Weight (in air)	13000 lb

To ease transportability, the SHS must be broken into easily assembled components that can fit within a 8 x 8 x 20-ft space envelope with a 150-lb/ft^2 deck loading.

The SHS module components must be easily arranged to fit on a ship of opportunity.

The SHS must be easy to operate and maintain by Navy personnel.

The maximum A-frame design load must be 30,000 lb and the maximum static tether load must be 7000 lb.

DEVELOPMENTAL HISTORY

Preliminary design began in 1986. Testing on a pier with a dummy vehicle began in May, 1987. Ocean testing of a preliminary SHS test configuration without the traction winch and 23,000-ft tether was conducted from Sep. through Nov., 1987 (Yumori, 1988). Sea states 0 - 3 were available at different sites near the island of Oahu. Pierside and sea state 0 tests were performed in Kaneohe Bay. Sea state 1 and 2 tests were performed on the leeside. Sea state 3 tests were either out of the lee or on the windward side. The following number of launches/recoveries were performed:

Pierside	20
SS-0	10
SS-1	8
SS-2	13
SS-3	12
Total	63

Ocean testing with the actual ATV vehicle and the completed SHS began in March 1989 as part of the ATV Test and Evaluation (T and E). In May 1989, the tether was conditioned, and the SHS was load-tested by lowering the tether in 18,000-ft depth and allowing the tether to freely rotate to release any residual construction stresses. There were 21 T and E dives, which included

DIVES	DEPTH (ft)	DURATION (hrs)
1	8400	72
8	15000	15
1	18980	6
1	20600	10

SYSTEM DESCRIPTION

The ATV system consists of the vehicle, SHS, vehicle tether, control van, and auxiliary equipment such as transponders, generators and maintenance van (figure 1) (Hoffman and Morinaga, 1991). Total system weight is as follows:

Vehicle + Dolly	14000
Control Van	17000
SHS	65000
Auxiliaries	38000
Total	134000 lb

The SHS consists of the lift-line and subsystems for the ram tensioner, A-frame, traction winch and storage drum, control stations, and motor pump (figures 2 and 3). Total required SHS deck area is 900 ft^2.

Vehicle Tether

The electro-optical-mechanical tether provides power, commands and data communications to the vehicle. The tether is a towline for the vehicle on the surface and acts as a tagline during launch and recovery. The tether contains three fiber optic fibers, three power conductors, and a Kevlar (registered trademark of DuPont) strength member. The tether is covered by a yellow jacket that provides better visibility at night on the video monitors. The ship's operator watches cable angle to the water as a maneuvering aid. Cable mechanical characteristics are

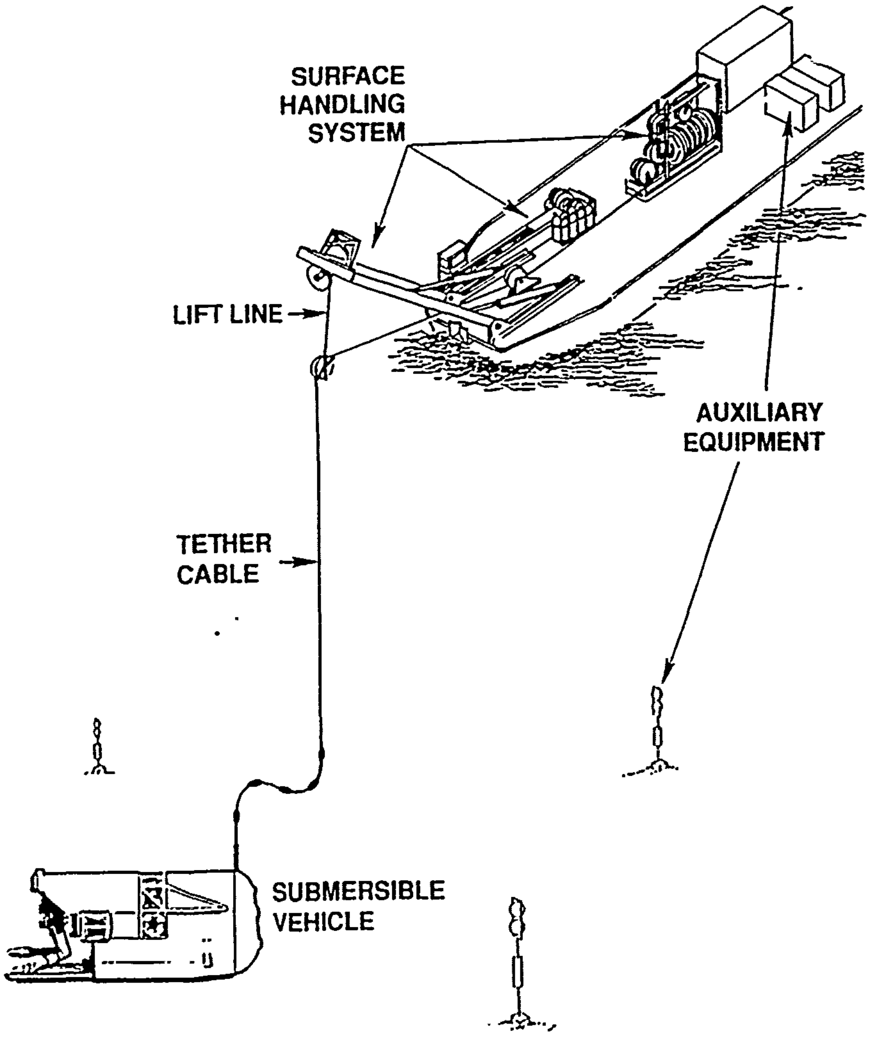


FIGURE 1 ATV SYSTEM CONSISTING OF VEHICLE, SURFACE HANDLING SYSTEM, CONTROL VAN AND AUXILIARY EQUIPMENT.

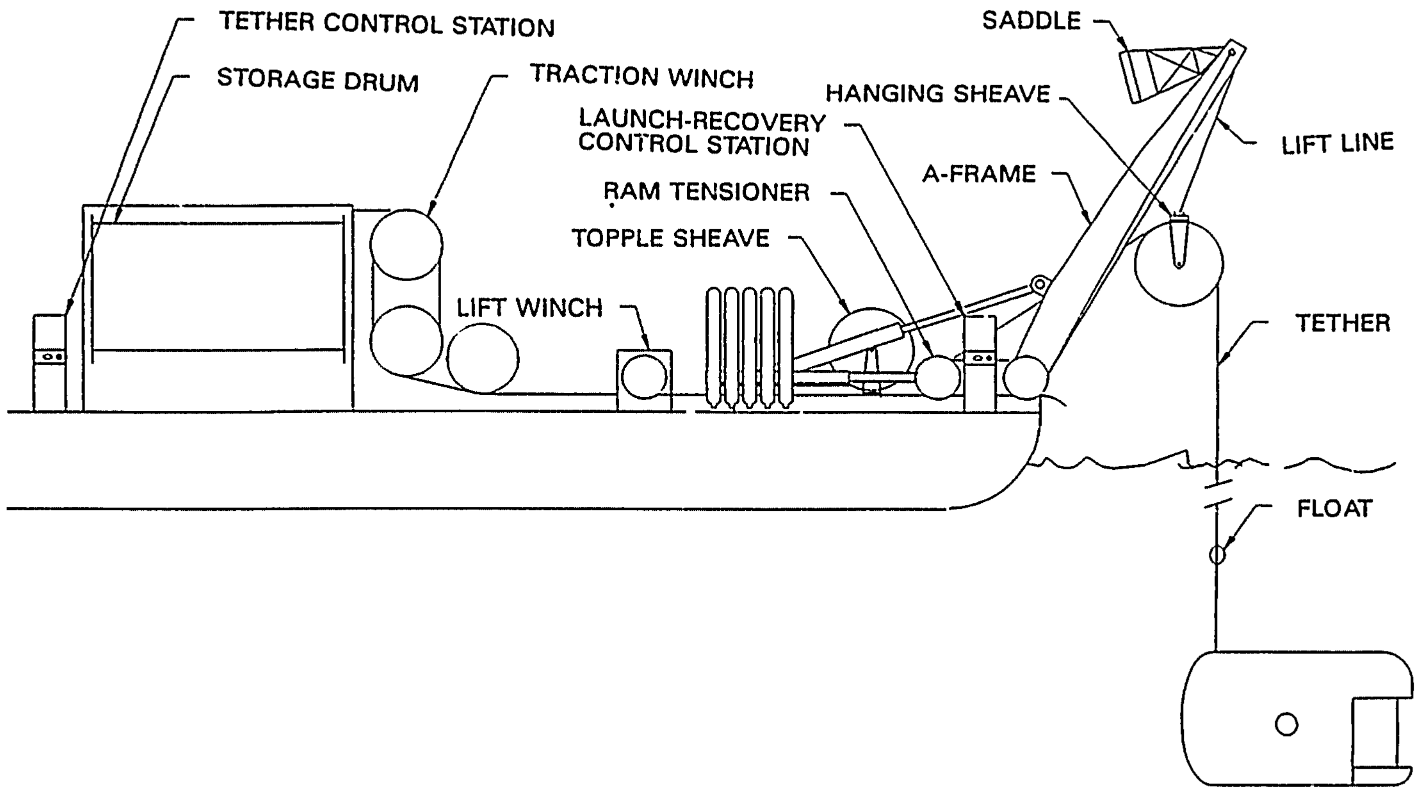


FIGURE 2 SURFACE HANDLING SYSTEM CONSISTING OF TETHER, LIFT-LINE, A-FRAME, RAM TENSIONER, CONTROL STATIONS, TRACTION DRIVE, STORAGE DRUM, AND MOTOR PUMPS.

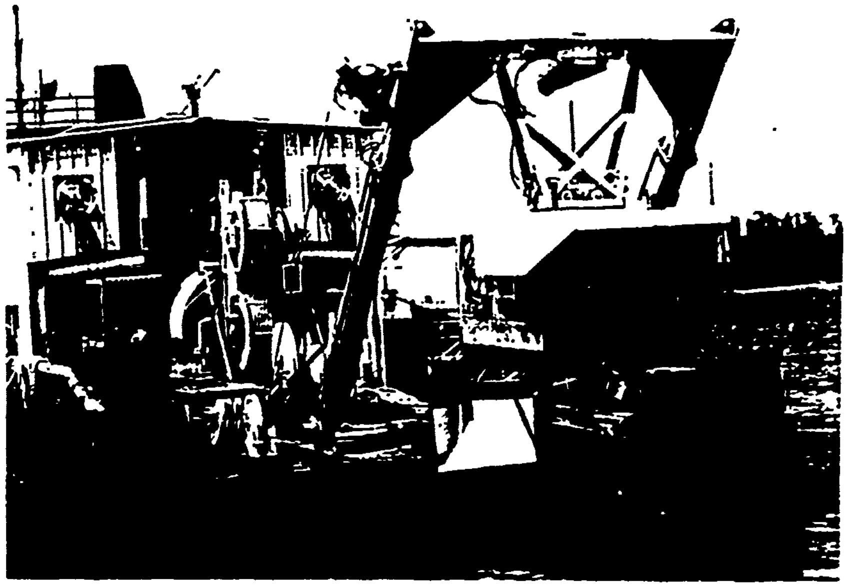


FIGURE 3 SURFACE HANDLING SYSTEM ABOARD THE MARSEA FIFTEEN

Diameter	1.23	in
Weight (in-air)	0.834	lb/ft
Weight (in-water)	0.308	lb/ft
Break Strength	50,000	lb

Lift Line

A 1-in dia. steel lift-line is used to launch and recover the vehicle, and also suspend the tether in a hanging sheave for tension compensation (see System Operation). The lift-line is a Warrington-Seale, 6 x 36, right regular lay, XIMP, bright construction with a 110,000-lb tested break strength.

Ram Tensioner Subsystem

The ram tensioner system prevents snap-loading of the lift-line during deployment and recovery, and also snap-loading of the tether cable during operations.

The ram tensioner subsystem is composed of a 7-in bore, double-acting hydraulic cylinder with a 6-ft stroke; a 20,000-lb pull lift winch; 28.25-in diameter Nylatron (registered tradename for Polymer Corp.) sheaves; two 10-gal accumulators and a 2.5-gal make-up accumulator. The ram cylinder has cushioned stops to prevent cylinder damage if the lift-line breaks. Also, the sheaving arrangement will cause the cylinder to retract if the line breaks.

The hydraulically powered lift-line winch has a maximum 1-ft/s line speed. A fail-safe brake will automatically engage when hydraulic power is lost. The brake will slip the winch if tension increases above 30,000 lb to prevent damage to the A-frame if the tether cable is snagged.

The tether and lift-line sheaves are made of Nylatron for low dynamic weight, corrosion resistance, and increased steel lift-line fatigue life. Fatigue testing (168-hr [168,000-cycles]) on the steel lift-line demonstrated 97% residual strength with Nylatron sheaves vs. 76% residual strength with steel sheaves. The tether sheaves are 48-in diameter and the lift-line sheaves are 28.25-in diameter.

A-Frame Subsystem

The A-frame module includes the A-frame, A-frame base, A-frame cylinders, lift-line sheaves mounted on the A-frame, a hanging sheave, the saddle, and latches.

The A-frame is constructed from steel rectangular tube. Two double-action hydraulic cylinders pivot the A-frame over center. Valves lock the cylinders if there is a hydraulic failure. For shipping, the crosspiece is unbolted. The upright beam and hydraulic cylinder on each side collapse almost flat and are shipped as one unit.

The saddle supports the vehicle and keeps it from swinging side to side. A fail-safe latch mechanism secures the saddle to the vehicle. The over-center latches are locked by the weight of the vehicle. They need positive hydraulic ac*uation to release. Four shock absorbers dai.., any pendulation and cushion the vehicle as it contacts the saddle.

Traction Winch and Storage Drum

The hydraulically powered traction winch and tether storage drum were originally designed for the RUWS system. Changes for the ATV were two on-axis, fiber-optic commutators; a new commutator for three-phase power; addition of a 1000-lb constant tension mode to the traction winch; and a change of the supports to allow the traction winch to be operated while separated from the storage drum. None of the grooving had to be changed, because coincidentally, the new ATV tether was the same diameter as the RUWS tether.

Control Stations

There are two fixed control stations and a handheld one. The handhelo control is used by an operator on the deck to control the tether with the traction winch as the vehicle is transferred by the A-frame and as the flotation is attached and removed from the tether.

The Launch/Recovery Control Station (LRCS) controls the A-frame, ram tensioner, lift winch, safety latches, and traction winch. It is located near the stern so that the operator can have a good view of the lift-line winch, the ram tensioner, the A-frame, the deployment area of the deck, and the vehicle while it is in the water at the stern of the ship. The controls are located inside a small enclosure that will protect the operator from tether or lift-line breakage.

The Tether Control Station (TCS) monitors and controls the tether reeling and unreeling from the storage drum and also monitors and controls the ram tensioner pressure as the in-water tether weight changes. It is located in the control van. The TCS has a video display to monitor the storage drum and hanging sheave.

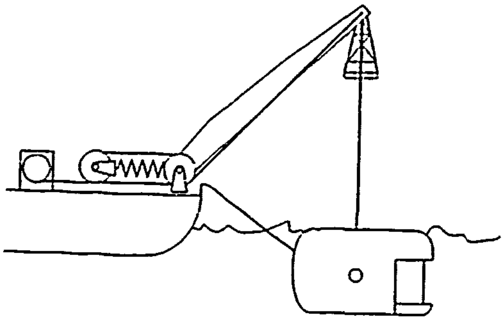
Motor Pump Module

The motor pump module supplies the hydraulic power to the SHS subsystems. There are two separate hydraulic systems - the traction winch hydrostatic transmission and the system hydraulics for the SHS.

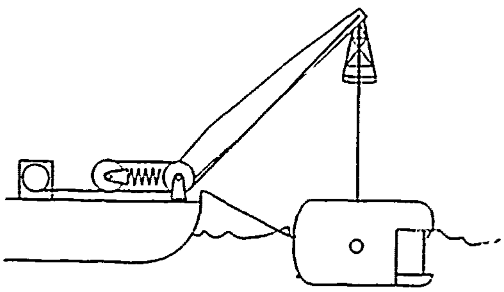
The two hydraulic systems share a common 200-gal hydraulic reservoir. Each hydraulic system comprises two motor pump units, working in parallel. Each motor pump unit supplies half the maximum required hydraulic power for its system. This arrangement provides 50% redundancy. If one motor pump fails, the other one is still able to provide 50% of the required volume.

RAM TENSIONER OPERATION

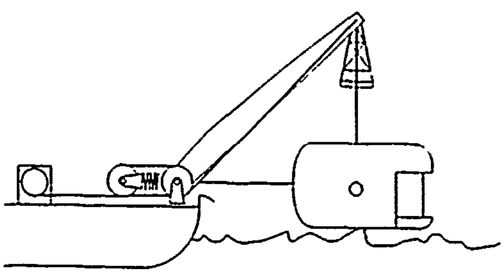
The lightweight structure of the SHS is protected by the ram tensioner from high dynamic loads by preventing snap-loading. Figures 4A-C illustrate operation of the ram tensioner to prevent snap-loads during recovery. When the vehicle is recovered, it has over 12,000 lb of entrained seawater that must be drained. Also, the lift-line must be kept taut to prevent snap-loading as the vehicle is pulled from the water. The ram tensioner is a spring that creates greater tension as it is compressed. Initially, the spring is fully extended (figure 4A). As the lift winch pulls on the lift-line, the ram compresses and pulls the vehicle with increasing force. As the vehicle is raised from the water, more and more water is drained, and the vehicle raises higher (figure 4B). The ram tensioner compensates for ship relative motion and keeps a steadily increasing force on the lift-line. Eventually, the vehicle is pulled free of the water (figure 4C). The ram tensioner also limits the tension as the vehicle contacts the saddle.



A. BEGIN RECOVERY
PULL WITH WINCH
RAM COMPRESSES



B. WATER DRAINING
RAM COMPRESSING



C. OUT OF WATER
RAM COMPRESSED

FIGURE 4 TENSION CONTROLLED RAM TENSIONER RECOVERY

SYSTEM OPERATION

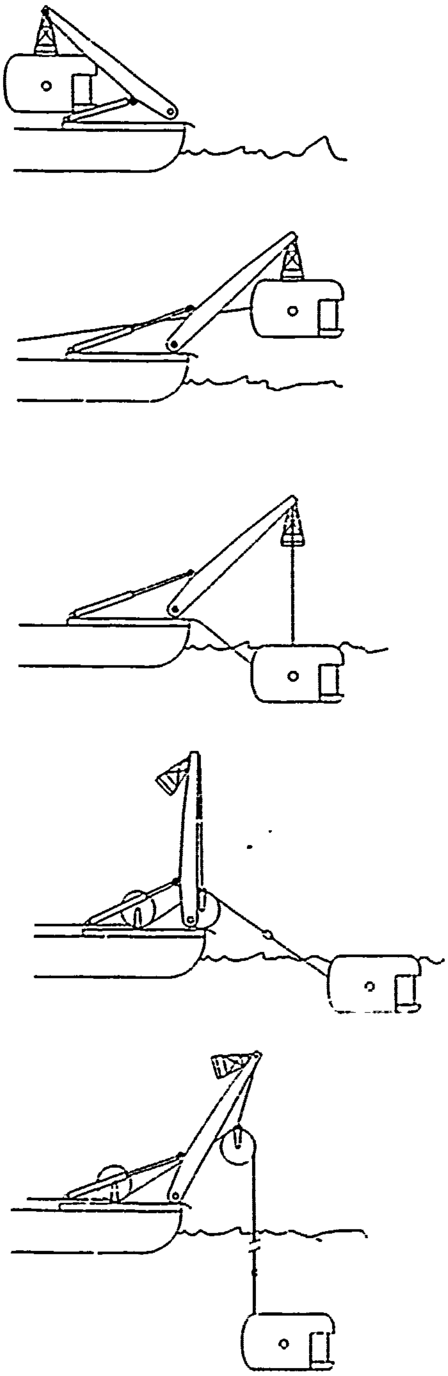
Operation of the SHS is illustrated in figures 5A-E. The ATV is lifted from the deck by the lift-line, up to the A-frame saddle (figure 5A). The ATV is latched securely to the saddle. The A-frame is pivoted over center until the vehicle is over the protected waters just aft of the ship stern (figure 5B). The vehicle is lowered after releasing the latches (figure 5C). During the deployment, the ram system prevents snap-loading of the lift-line. The support ship will be underway into head seas at a nominal speed of 1 knot or less during the deployment. As the vehicle enters the water, the hydrodynamic drag on the vehicle forces it away from the ship stern. The tether passes along the deck, over a fairlead trough, down to the vehicle. The tether acts as a tagline to stabilize the vehicle as the vehicle enters the water. When the vehicle is completely in the water, the lift-line is removed from the top of the vehicle.

Floats are attached to the first 400 feet of tether to create a whip. The support ship continues underway at a nominal speed; the floats are attached at set intervals to the tether as the tether passes along the ship stern deck (figure 5D).

Once the vehicle is ready to begin its dive, the SHS is prepared for its operating mode, by attaching a hanging sheave and capturing the tether with a topple sheave. The tether passes along the deck, under the topple sheave, up to a hanging sheave, and down to the water. The hanging sheave is supported by the lift-line. The lift-line is supported by the ram system (figure 5E). The ram system will tension-compensate the tether to prevent snap-loading. The ram system is adjusted periodically to compensate for the change in the weight as the tether is deployed.

The recovery proceeds in the reverse order of the deployment. The lift line hook is attached to the vehicle lift bale by using a 20-ft long pole.

For launch and recovery, there is one operator in the LRCS, one operator with the portable control station on the deck, and two deck hands to attach and remove the flotation. During the dive portion, there is



(A) LIFT VEHICLE INTO SADDLE

(B) SWING VEHICLE AFT
LOWER VEHICLE WHILE
UNDERWAY AT 1 KNOT

(C) PUT TETHER INTO CHUTE

VEHICLE IS TOWED
WHILE WHIP IS MADE UP

STOW AWAY SADDLE

(D) AFTER WHIP IS MADE UP
INSERT TETHER INTO
HANGING SHEAVE AND
TOPPLE SHEAVE

(E) HANGING SHEAVE IS
SUPPORTED BY LIFT LINE
AND RAM TENSIONER

FIGURE 5 OPERATION OF SURFACE HANDLING SYSTEM

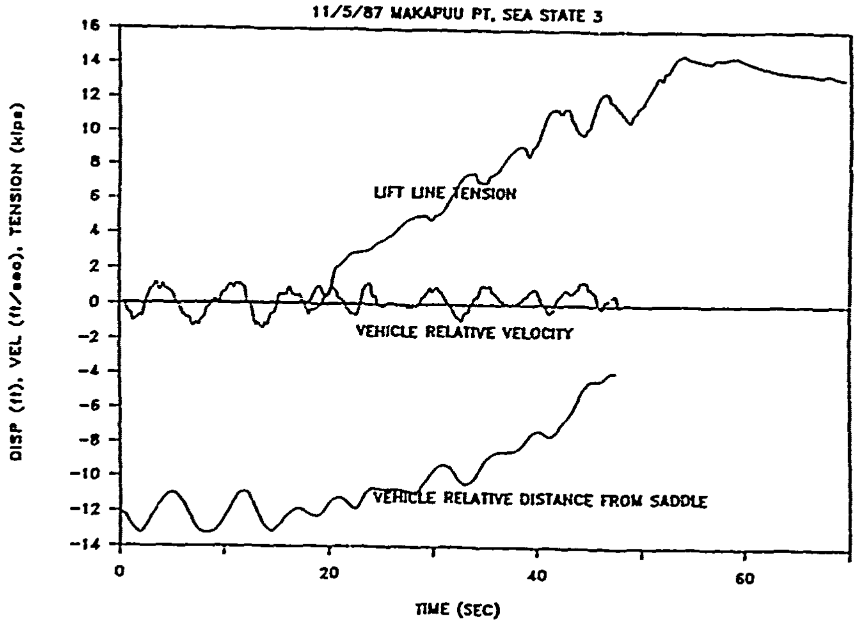


FIGURE 6 LIFT-LINE TENSION, AND RELATIVE MOTIONS DURING SEA STATE 3 RECOVERY

one operator at the TCS in the control van who does periodic deck inspections.

SYSTEM MODULARITY

The SHS was designed with a high degree of system modularity to meet the transportability requirements and to accommodate a variety of deck layouts for ships of opportunity. The traction winch and storage drum can be separated and rotated for greater layout flexibility.

SAFETY CONSIDERATIONS

There are several safety features in case of failures.

Loss of Hydraulic Power
- A-frame cylinders lock.
- Lift winch brake locks.

Tether or Lift-Line Break
- Ram retracts.
- Flow control limits ram speed.
- Cushioned stop on ram.

Tether Snag
- Ram absorbs sudden shock.
- Lift winch slips to limit tension.

SYSTEM TESTING

Preliminary SHS Test

The preliminary SHS test objectives were to verify launch/recovery in sea state 3; determine tow characteristics of vehicle; verify anti-snap-load capability of ram tensioner subsystem; and develop operator training requirements.

The ram tensioner worked well to limit high tensions by preventing any snap-loads during the launch and recovery. Figure 6 shows the lift-line tension, relative motion and velocity between the A-frame and vehicle in a sea state 3 recovery. The relative motion was measured by a sensor line between the A-frame and vehicle. The ram tensioner limited maximum tension to 15,000 lb. Relative motion varied +/- 1 ft, and relative velocity varied +/- 1.5 ft/s.

Three operators were trained in 2 days and easily performed launch/recovery in high sea state 2.

The vehicle towed stably, but there were up to 7000-lb towing snap-loads as the vehicle surfed down the face of a wave and plowed into the rear of a wave. (Note: The ram tensioner was not attached during this phase (Figure 5C).

Final Demonstration Testing

The final testing objective was to demonstrate the complete SHS system meeting its operational requirements. There were early problems of high towing snap-loads (greater than 10,000 lb) and termination failure in the Kevlar lift-line. The high snap-loads occurred while the vehicle was very close to the ship. These snap-loads were not experienced in the preliminary tests. The ATV vehicle is 1500 lb heavier than the dummy and tended to plow into the waves more than the dummy. The high snap-loads were reduced by using a 1000-lb constant tension, "soft" mode on the traction winch that released tether during snap-loads, and by changing recovery procedures. The termination problem was caused by insufficient braid length to develop full strength in the braided termination. The termination problem was eliminated by changing to steel line and using a swaged termination.

20,600-ft Dive

The final SHS test occurred during the 20,600-ft dive on 2- to 3- June 1990 in the Molokai Fracture Zone, 500-nmi east of Oahu. The launch sea condition was a sea state 2 (2- to 3-ft wave height at 6 s/cycle with 3- to 4-ft swells). The recovery was in a very confused high sea state 3 (3- to 4-ft wave height with up to 10-ft swells coming from three different directions).

Figure 7 illustrates the dive timeline. Total dive time was 22 hours. Launch and attaching floats took 45 minutes. The vehicle touched bottom at 20,600 ft, 5 1/2 hours after launch. After SHS tests and checkouts, the vehicle transited 1 nmi to a dead transponder. After 12 hrs on the bottom, the vehicle started its ascent. It delayed at 16,000 ft for additional SHS tests. Removal of floats and recovery took 1 hour. The maximum snap-load during towing was 6000 lb.

Figure 8 illustrates the effectiveness of the ram tensioner in reducing the tether tension variation. Under similar ship motions at 20,600 ft, when the ram tensioner was locked, the maximum tension variation was 5250 lb vs. a maximum variation of 2100 lb after the ram was activated. The ram tensioner removed 60% of the variation.

CONCLUSIONS

1. Testing has demonstrated that the system is easy to operate in sea state 3.

2. The use of the ram tensioner to eliminate snap-loads and prevent high lift-line tensions and shock absorbers to dampen vehicle pendulation greatly reduces the amount of operator skill and judgment needed for launch/recoveries.

3. The ram tensioner is able to eliminate up to 60% of the tension variation and thereby reduce the possibility of snap-loading at depth.

4. The lightweight Surface Handling System has fulfilled all of its operational requirements.

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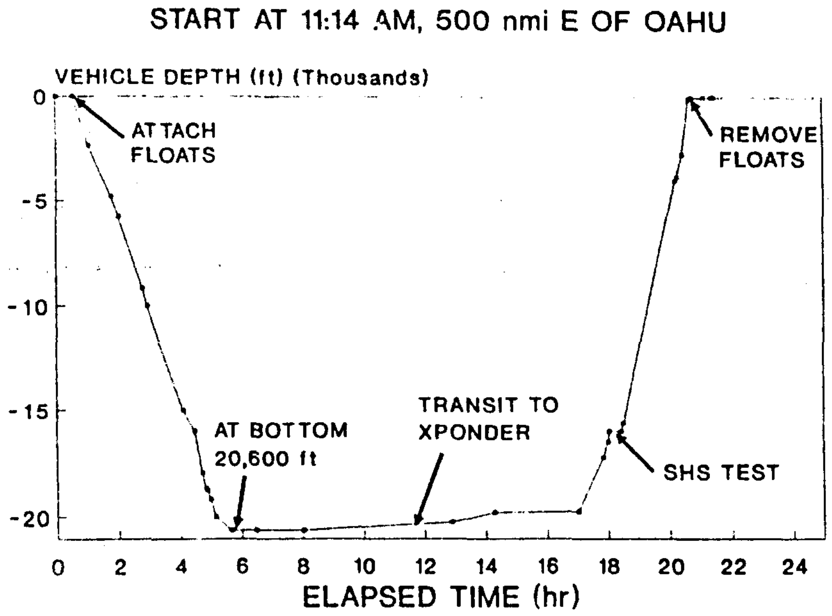

FIGURE 7 20,600-ft DIVE TIME LINE FOR 2 JUNE 1990

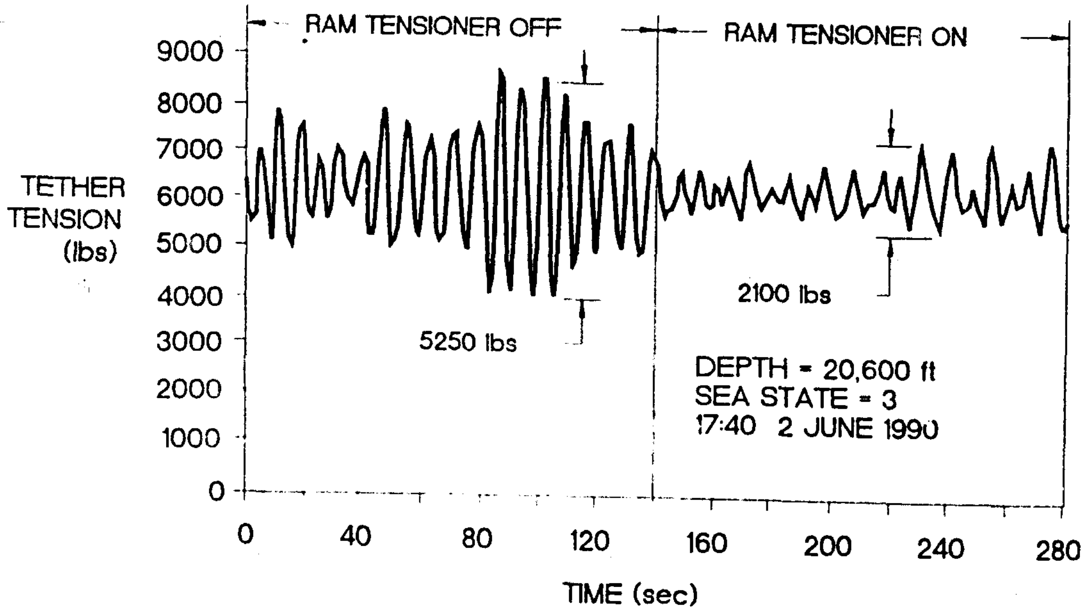

FIGURE 8 RAM TENSIONER FROZEN VS. RAM TENSIONER ACTIVE